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Research Department Report

The first year's work of RACE project 1036 WTDM broadband customer premises network

Edited by A. Oliphant, M.A., C.Eng., M.I.E.E.

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

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Summary

This Report describes the first year's work on RACE Project 1036. The aim of this project is to develop a Broadband Customer Premises Network (BCPN) suitable for broadband service providers and for a wide range of applications in industry, commerce, education, and public services. The BCPN uses a combination of wavelength-division multiplexing and electrical time-division multiplexing to give a total capacity on a single bearer of over 38 Gbit/s.

During the first year a detailed Technical Specification has been agreed by the Partners. Technical progress is reported in electrical multiplexing up to 2.5 Gbit/s, control and packaging of high speed laser transmitters, optical star couplers, optical demultiplexers, optical receivers, and system control.

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1. INTRODUCTION

RACE (R & D in Advanced Communications-technologies in Europe) is a five-year programme sponsored by the Commission of the European Communities[1]. Its object is to make technology available for the building of a Europe-wide digital communications network using optical fibres — the Integrated Broadband Communications Network (IBCN). RACE is organised into projects, each dealing with an aspect of the IBCN; each project must include partners from at least two of the countries of the European Economic Community (EEC). Work on RACE projects is 50% funded by the Commission of the European Communities.

The aim of Project 1036 is to develop a Broadband Customer Premises Network (BCPN) suitable for broadband service providers, such as broadcasters, and for a wide range of applications in industry, commerce, education, and public services. The BCPN uses a combination of optical wavelength-division multiplexing and electrical time-division multiplexing to give a total capacity on a single bearer of over 38 Gbit/s. The availability of such a BCPN capable of carrying a mixture of digital signals with bit rates up to that of HDTV will encourage large-scale use of the IBCN for transmission of video signals to ensure its viability in the early years.

This Report describes the first year's work on the Project. It is based on the Project's confidential Annual Review Report, compiled from contributions from all the Partners and submitted to the RACE Central Office to form the basis for the Project Annual Audit before a panel of independent experts. It is now published in revised form as a non-confidential Research Department Report with the agreement of all the Partners.

1.1 Partners in R1036

Prime Contractor:

British Broadcasting Corporation

Partners:

Alcatel Standard Eléctrica SA (*Spain*)
GEC Hirst Research Centre (*UK*)
Instruments SA, Division Jobin-Yvon (*France*)
PTT Dr Neher Laboratories (*Netherlands*)
SGS-Thomson Microelectronics (*France*)
STC Defence Systems (*UK*)
STC Technology Ltd (*UK*)
Thomson-CSF Laboratoires Electroniques de Rennes (*France*)

1.2 Principal achievements of the first year

The work of R1036 concentrates on systems aspects, but includes development of the enabling technology where suitable devices are not available. The following brief summary of the first year's achievements may be clarified by reference to the description of the principles of the BCPN given in Section 2.1. During the first year:

- **a detailed Technical Specification of the system and detailed procedures for testing individual devices and the whole network have been agreed by the Partners,**
- **a prototype laser control board and laser package have been tested, circuit design of the electrical multiplexer and demultiplexer has been completed, and an IC for interleaving and disinterleaving signals up to 2.5 Gbit/s in silicon has been designed to gate level,**
- **wavelength-flattened 2 × 2 and 4 × 4 fibre couplers suitable for use in a 16 × 16 star coupler have been fabricated and tested and half of a 16 × 16 coupler has been fabricated,**
- **a design study on a planar waveguide star coupler and demultiplexer has been carried out and prototype 2 × 2 couplers have been made,**
- **a fibre-coupled wavelength demultiplexer has been fully specified for use in the Project,**
- **a wavelength demultiplexer directly coupled to an array of diodes is being investigated, and a target specification for it has been completed; diode arrays from RACE Project 1027 have been successfully mounted on a breadboard grating demultiplexer for initial assessment,**
- **two types of photodetectors — a PIN diode and an APD — have been compared for use in the receiver; only the APD is sensitive enough to give a sufficient power margin,**
- **a Report on IBCN interface standardisation has been written,**
- **the textual description of the control system and the first description in Specification and Description Language (SDL) have been completed.**

2. OBJECTIVES

2.1 General objectives of the Project

The aim of this project is to develop a Broadband Customer Premises Network (BCPN) suitable for broadband service providers and for a wide range of applications in industry, commerce, education, and public services. As mentioned above, the work will concentrate on systems aspects, but will include some development of devices that are not yet available on the market. Reference 2 gives an example of the use of the BCPN as a signal routing and distribution system in a television studio centre.

The BCPN is based on a number of local routing centres (LRCs), each serving several sources and destinations. The signals from the sources are time-multiplexed electronically at the LRC to form a serial bitstream with a gross bit rate up to about 2.5 Gbits/s (payload about 2.4 Gbit/s). The electrical multiplexing will follow relevant CCITT Recommendations.

This serial signal modulates a distributed feedback (DFB) laser. A different wavelength is used at each LRC, the wavelengths being equally spaced a few nanometers apart. The outputs of all the LRCs are combined in an optical star coupler to give a wavelength multiplexed optical signal. The optical signals are then distributed to each of the LRCs where they are demultiplexed optically and electrically to provide access at each of the destinations to signals from any of the sources in the system. The network uses single-mode fibre operating in the 1500 nm wavelength window. Functional schematics are given in Figs. 1 and 2.

Control software will allow selection of any source at any destination without centralised switching. This software will control the network, enabling it to perform all the functions required. For each specific application extra customer control software will be needed to translate the customer's control procedures into the commands required by the network control.

One or more of the LRCs will form an IBCN interface to exchange signals with the IBC public network according to CCITT Recommendations. This interface will include exchange of signalling between IBCN signalling channels and the BCPN control software.

Combining both wavelength and time-division multiplexing (WTDM) in this way extends network capacities considerably, without stretching either technique beyond what can be demonstrated in a practical system within RACE timescales. The WTDM system uses fibre optics to the best advantage — the transmission of high bit rate signals with little loss — and uses electronics efficiently in multiplexing, demultiplexing and data selection. It is an economic intermediate stage between existing technologies and more advanced, even higher capacity, systems based on optical frequency-division multiplexing and coherent detection.

Several different configurations of the BCPN are possible to suit different applications. Networks can be connected in series or in parallel, either to provide more sources and destinations or to interconnect networks in different areas.

The WTDM system could also be used in the interactive cable TV networks of the future. For final distribution to the home lower quality standards than those that will be used in programme production are acceptable and a lower bit rate per channel will almost certainly be used. The system could also handle distribution of HDTV signals in cable TV networks at an appropriate bit rate.

The Project is planned to produce an interim test bed at 3 years which will demonstrate the key concepts of the system design, principally the optical components. A more heavily populated test bed will be produced at 5 years which will demonstrate all aspects of the network, exercising all the critical elements of the system specification. The development of these test beds will include some environmental testing of the system and all its components.

In order to construct these system test beds, it is necessary to specify, acquire and, in some cases, develop components and control software that will conform to the system specifications. This work is divided into nine sub-projects: system specification, electrical multiplex, laser transmitter, optical coupler, optical demultiplexer, optical receiver, electrical selector matrix, IBCN interface, and control. An important assumption in the final planning of the Project was that technology for clock regeneration and electrical switching at 2.5 Gbit/s would be available either from other RACE projects or from outside RACE; clock regeneration was therefore deleted from the Project plan in order to meet cash limits.

2.2 Specific objectives of the first year's work

The Project objectives for the first year, largely taken from the first year workplan in the Technical Annex to the RACE contract, are listed below by sub-project. Section 4, which follows the same numbering, gives the progress made in each sub-project during the first year.

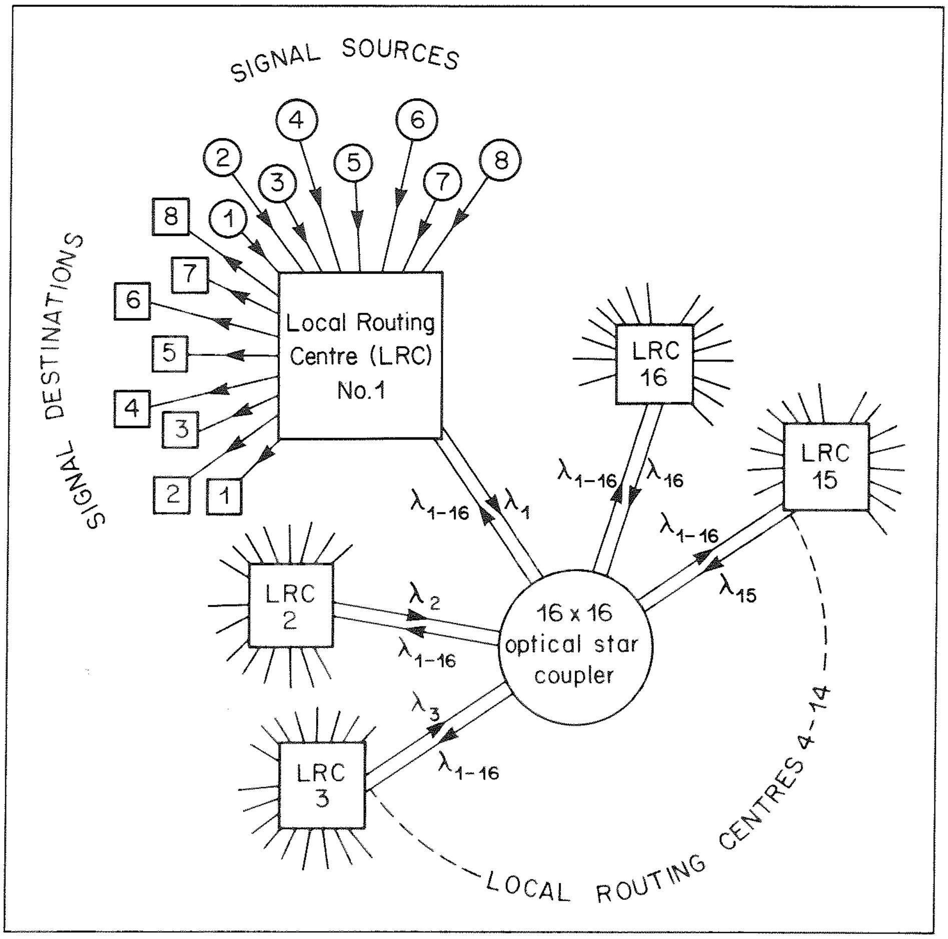


Fig. 1
A WTDM routing system.

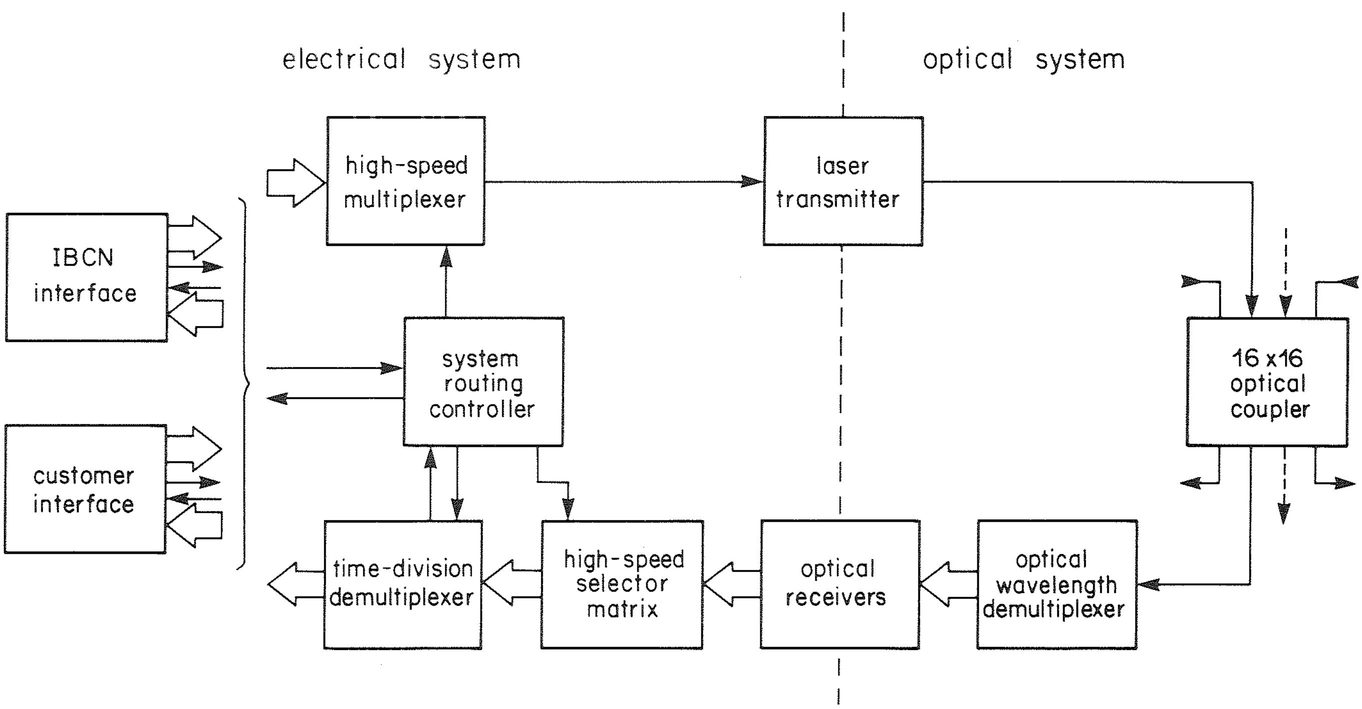


Fig. 2 - Functional block diagram of the WTDM system.

2.2.1 Technical specification

To agree a target system specification, covering electrical, optical, and control aspects. To determine basic test procedures and to select or devise suitable test and measurement equipment.

2.2.2 Electrical multiplexer/demultiplexer

To specify and design functionality of multiplexers from 300 Mbit/s to 2.4 Gbit/s. To establish gate level descriptions and logic simulations. To make a choice between silicon bipolar 1.2 μm, 1.0 μm, and 0.8 μm processes. To start detailed design based on interface and functional specifications.

2.2.3 Laser transmitter

To produce a technical specification for the laser submount which is consistent with the aims of Project 1027. To develop a package capable of 2.4 Gbit/s operation, incorporating 50 Ω input impedance via SMA connector, thermo-electric cooler and sensing element for temperature control, and internal rear facet monitor diode for power control. To produce prototype circuits for controlling both the laser temperature and the mean power.

2.2.4 Star coupler

To develop a 16 $\times$ 16 star coupler based on the fused fibre technique and to produce half of a 16 $\times$ 16 coupler. To investigate the potential for low-cost reproducible star couplers in planar waveguide technology.

2.2.5 Optical demultiplexer

To prepare a specification for a bulk grating demultiplexer fulfilling the predicted system design requirements and to produce fibre arrays and master gratings to be used in manufacturing a prototype fibre-coupled demultiplexer. To complete the initial stages of the design and development of a diode-coupled optical demultiplexer and produce a target specification; to begin assembly of a breadboard four-channel demultiplexer compatible with progression to 16 channels.

2.2.6 Optical receiver

To prepare a specification for the optical receiver in the light of available technologies and techniques. To start design of a transimpedance preamplifier.

2.2.7 Selector electronics

To prepare a specification for the selector electronics in the light of available technologies and techniques.

2.2.8 IBCN interface

To acquire an overview of IBCN interface standardisation.

2.2.9 Control

To define the services provided by the network (e.g. connection, booking) in terms of attributes. To provide a formal testable description of the bearer service control. To provide the microcomputer and ancillaries on which the control system will be based.

3. RELATIONSHIP WITH THE RACE PROGRAMME

3.1 Role of the Project in the RACE programme

The RACE programme is organised in three parts. Part I deals with strategies for the development and implementation of the IBCN; this Part is intended to cover the development of functional specifications for the network and its services, and research aimed at the definition of standards for the IBCN. Part II deals with IBCN technologies: it covers pre-competitive research and development to bring forward new technology for the low-cost realisation of IBCN equipment and services. It includes, for example, the development of high-speed electrical and optical transmission, switching and multiplexing, video coding and displays, cryptology, and network management and control. Part III is entitled 'Pre-normative functional integration' and aims at assessing functions, operational concepts and experimental equipment with respect to the functional specifications and standardisation proposals arising from the work in Part I — in other words, seeing if it all works together.

The R1036 Project role in RACE is best described in terms of the structure of the RACE programme. It contributes in two technical areas, namely, Optical Communications and IBC Customer Systems. It is a Part II technology project and primarily aims to establish and verify a system concept.

As a system project in optical communications, the key research objectives are to develop the wavelength division multiplex technique, to identify a maximum capability and to approach this, furnishing the particular optical components for a practical and viable realisation. The resulting optical chain is the core of the Broadband CPN.

The WTDM BCPN is envisaged as the technological basis for the signal distribution of digital video, audio and data traffic which will appear, in a

variety of combinations, in future customer premises. The CPN might be described by application or generically, i.e. domestic, business, community services, public services. The system innovative thrust is to provide the capability for very high bit rates, greater than 2 Gbit/s and to exploit very specifically the technique of time division multiplexing of many signals over a single bearer link — including the connection to the IBCN via a user interface designed in the Project.

The RACE Workplan for 1989[3] shows R1036 as contributing to tasks 272, 274, 280, and 288, and, in particular, task 284 where it is shown as the only project for the high bit rate link—customer access connection.

3.2 Interactions with other RACE projects

The principal links to other projects were established within the groupings set up for Concertation (this is the term used for the series of meetings intended to ensure that the RACE programme as a whole forms a coherent view of the development of the IBCN). In the CPN Group the key interactions so far relate to the common interest with R1018 HIVITS (which is developing bit-rate-reduction codecs for video signals ranging in application from videophone to HDTV) in establishing formats and interfaces for video and audio; i.e between the signal origin and the point where bit-rate-reduced formats may be introduced for long distance transmission. Inter-operability of video and audio systems is an area discussed with R1041 FUNCODE partners, possibly to exploit R1036 background art in matters such as synchronisation and standards conversion.

Since R1036 is establishing a synchronous architecture, a matter of concern is to monitor the development of Asynchronous Transfer Mode (ATM) both in the CPN environment and in the public network through contacts with R1022 (which is developing technology for ATM). R1036 is taking part in CPN workshops organised by the RACE Central Office (RCO) which aim to bring together different CPN projects and Part I so that common interests such as network topology, S and T reference point interfaces, and network protocols can be pursued in the interests of compatibility at strategic, system and standards levels.

R1036 also has representation in the Optical Group at Concertation Meetings. The strength of presence of the Project within the CPN Group is equally manifested in the Optical Group. This is mainly due to the wide extent of optical activities encompassed within the WTDM project. For a start, the system is based on a passive optical distribution network, a topology which is rapidly finding preference for the Customer Access Connection. The Project also entails the transmission of a relatively large number of channels using tightly packed wavelength division multiplexing. The system will use DFB lasers modulated at bit rates in excess of 2.4 Gbit/s. To realise such a system, the Project will develop the specialised passive optical components such as the star coupler and wavelength demultiplexers using bulk optic and integrated optic technologies. The work in R1036 is likely to establish the limits of performance of these components. An approach to integrated optical devices is being made for the wavelength demultiplexer and for the star coupler.

It is precisely due to these factors that Project 1036 has been noted within the Optical Group as being of special interest to almost all the projects involved in this group. This interest is clearly mutual as some of the technologies researched within other optical projects would be relevant, important, and in some cases essential for the continued success of this programme.

At the request of the Optical Group, a presentation describing the Project and its objectives was given at the beginning of the year. The outcome of this exposure, as well as subsequent meetings has led to further separate meetings between the Project and individual projects to discuss specific topics of common interest.

Apart from contacts made at Concertation Meetings, the main interactions with other RACE projects have involved transfer of 'deliverables' from one project to another. These deliverables, which may be devices, reports, or software, are the formal results of the work of the projects. A list of all deliverables in all projects is maintained by RCO; any project may ask to receive a deliverable in another project that it regards as necessary to its work. For R1036 these contacts are listed in the following two sections.

3.2.1 Deliverables from R1036 to other projects

During the second Concertation Meeting a contact was established with R1044 group 1.2. This group was interested in the work done by R1036 on the structuring of bearer connections (see Section 4.9). This resulted in the sending of deliverable C1 to the members of this group on May 31 1988.

As mentioned in Section 3.2.2 below, software developed by R1036 will be used as a test case for the software development method being developed by R1023.

R1036 deliverables have been assessed for value to other projects and a matrix linking deliverables and projects has been contributed to the RCO database.

3.2.2 Deliverables from other projects to R1036

R1027 is providing dice for the DFB laser transmitters to be used in the system test bed; packaging of the lasers and control of their output wavelength and power for use at 2.5 Gbit/s is the responsibility of R1036. R1027 is also providing photodiode arrays for use in the diode-coupled optical demultiplexer that is being developed by R1036. Close liaison has been maintained with R1027; the technology developments are progressing well. Deliverables so far have been on schedule and no delays are foreseen in the future.

Considerable thought has been given to the possible adaptation of the HDTV switch being developed by RACE Project 1013 for use at 2.5 Gbit/s for signal switching of the R1036 high speed multiplex. This would overcome a weakness where budget limits have confined progress on this subject to a report deliverable (a survey of possible technologies and sources of appropriate purchasable hardware).

Work on the IBCN interface sub-project required a report from the Broadband User-Network Interface (BUNI) group R1044/2.1; contacts were established to obtain this report when it became available.

During the second coordination meeting a contact was established with R1023 (BEST) which aims to advise Part II projects on software issues. After a discussion it was agreed to use the formal software development method proposed by this project as soon as it was available. Their first report was completed in August 88 and will be made available to R1036. The software developed in R1036 will possibily be used as a test case for this system.

3.2.3 General interest contacts

A meeting was held with members of Project 1008, which is developing low-cost passive optical components, to discuss the integrated optics technologies developed by both projects. This contact has enabled a beneficial exchange of ideas and views with the aim of developing complementary technologies.

Informal discussions were held with the optical switching projects (R1033 and R1019) to discuss the feasibility of incorporating optical switching techniques within the proposed network principally as a substitute for a 16 $\times$ 8 electronic matrix for 2.5 Gbit/s signals.

Concertation discussions on the chosen passive topology and multi-channel WDM technique adopted in system projects such as ACCESS (R1030), which is investigating the customer access connection, BLNT (R1012 —Broadband Local Network Technology) as well as CMC (R1010 — Coherent Multi-Channel) were noted with the aim of reaching a unified concept of the Customer Access Connection.

There has been a positive response from COST Projects 216 and 218 to our request for an exchange of information on common areas of research interest. Four optical projects were approached: High Bit Rate Fibre System (215), Switching & Routing (216), Measurement Techniques (217) and Fibre Science and Reliability (218).

3.3 Contribution to the advancement of IBC

The aim of this Project is to encourage the large-scale use of the IBCN by developing a Broadband Customer Premises Network (BCPN) suitable for broadband service providers and for a wide range of other corporate users. Only corporate customers can generate the volume of traffic that is needed to ensure the viability of the IBCN in its early years, when demand from domestic customers is still small.

A potential application of the IBCN that could generate a large volume of traffic is the carriage of television signals both for programme contributions and for distribution to broadcast transmitters and cable-TV head ends. This application requires that service providers can route signals in their own premises in a form compatible with the IBCN — so a Broadband Customer Premises Network is needed. The BCPN that will be developed in this Project may find its first application in the television industry, but it will encourage the use of broadband video communications via the IBCN in industry, commerce, and education. Similar systems could also be used in the interactive cable-TV networks of the future.

4. PROGRESS

The progress of the work is described for each sub-project, following the order of Section 2.2.

4.1 System specification

Three meetings of all partners have been held to discuss the system specification. A detailed specification was completed and submitted to RACE on 6 July. This specification describes the BCPN and then specifies the performance of each of the components of the network and of the interfaces

between them. The specification will be kept under review throughout the Project, so that any changes that become necessary in the light of technical progress can be incorporated.

Test procedures are being defined in a separate work package; a test specification is now almost complete. A report discusses the revised allocation of Partners' effort in this work package.

4.2 Electrical multiplex

CCITT Recommendations G.707, 708, and 709 (formerly G.70X, 70Y, and 70Z) were agreed by CCITT Study Group XVIII just after the Project started and were adopted as the working assumption for the multiplexing technique. These draft Recommendations define a synchronous multiplexing hierarchy that can be used directly for conveying fixed bit rate video and sound signals in a BCPN. It is expected that CCITT SG XVIII will also define methods for transporting ATM signals in the synchronous hierarchy, so ATM could be used if appropriate in other applications of the WTDM system.

CCITT Rec. G.709 specifies a scrambler to randomise the data and break up very long runs of **1**s or **0**s. This scrambler has been simulated and a report written. Although the scrambler turns continuous **1**s or **0**s into a pseudo-random sequence, if fed with random data it can produce runs of **1**s and **0**s long enough to cause the source laser wavelength to drift (± 0.3 nm). Therefore G.709 is not the ideal choice for the WTDM system. However, because of the considerable benefits of using a CCITT standard scrambler, the problem of laser wavelength drift has been overcome by appropriate modification to the optical demultiplexer and the G.709 scrambler has been adopted by R1036.

Again for conformity with CCITT draft standards it has been agreed that the input signals to the multiplexer will be at the 155 Mbit/s STM-1 level rather than the 300 Mbit/s proposed in the Technical Annex before the hierarchical bit rates of the CCITT draft standards were known.

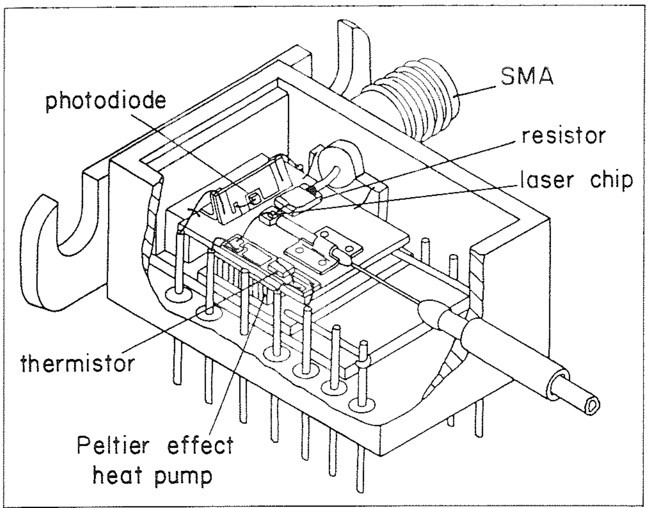
In the synchronous hierarchy, the higher levels are specified to be produced by octet interleaving of the 16 STM-1 levels (155 Mbit/s). Preliminary design work on the high-speed multiplexer showed that an octet-interleaving multiplexer would be a very complex IC compared to a bit-interleaving multiplexer — and this IC was judged by the Partners involved to be of limited commercial interest, in the time-scale of the Project. It was therefore suggested that as R1036 is a system project, the complexity of octet interleaving could not be justified and that bit interleaving should be used instead. There were misgivings, however, because of this departure from internationally agreed standards. Subsequent work showed that octet interleaving could be achieved by bit re-ordering at 155 Mbit/s followed by bit interleaving; and it was finally agreed that this extra circuitry should be incorporated so that the multiplex will remain compatible with CCITT draft standards.

Two high-speed ECL processes, HPIB4 and HF3C, have been evaluated in terms of density, power, and speed. Simulations of a 2:1 multiplexer and a D flip-flop have been performed; the HF3C process was chosen for the high-speed multiplexer IC. Work has continued on the generation of the multiplexer sub-system functional diagram and the layout of the basic cells for the multiplexer and demultiplexer; a design at gate level of an IC to perform interleaving, sync recognition, and disinterleaving of 16 STM-1 signals (that is, from 155 Mbit/s to 2.5 Gbit/s and back to 155 Mbit/s) is now complete.

Functional design of the multiplexer and demultiplexer assemblies (the circuitry that is required in addition to the high-speed IC) is also complete. This design work has included a studies of methods of bit re-ordering for octet interleaving and methods of achieving synchronisation in the high-speed demultiplexer.

4.3 Laser transmitters

Sample high-speed dual-in-line laser packages (as shown in Fig. 3) have been assembled and tested for high frequency operation: VSWRs of <1.4 at 1.5 GHz have been achieved. Temperature performance evaluation has demonstrated good fibre stability. 1300 nm Ridge Waveguide lasers mounted in these



Courtesy of STC Defence

Fig. 3 - Internal construction of a dual-in-line laser package.

high-speed DIL packages have been shown to operate to a BER of 10^{-9} at 2.5 Gbit/s with a $(2^{15}-1)$ PRBS. However the first DFB lasers in such packages show error floors under the same conditions. Preliminary investigations suggest that the problem is caused by low relaxation oscillation frequencies and the parasitic capacitance and inductance of the package. Devices with a shorter cavity were assembled to try to solve the problem, but showed no improvement. The problem is now thought to be due to the DFB's feedback mechanism; further experiments on why the DFB lasers are slower will concentrate on the zinc doping in the laser guide layer.

Prototype laser control circuits have been designed and assembled; evaluation of these circuits has revealed transients generated during power-up, so a slow-start circuit has been installed. Evaluation of the circuits with sample high speed DFB laser diode modules over the range 10 °C to 40 °C gives 3 °C change at the laser chip which results in an acceptable 0.3 nm wavelength change and insignificant power variations.

Samples of ICs to provide the high current drive needed to modulate the laser driver have been purchased for evaluation. However these ICs are specified to deliver 80 mA but only into a 10 Ω load rather than the 50 Ω impedance chosen for the laser. As an alternative a laser driver will be developed by the Partner responsible for the laser.

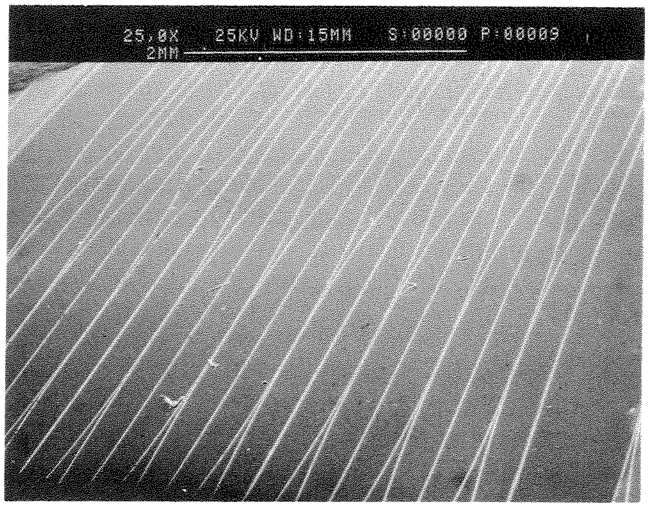
A time resolved spectroscopy facility has now been established and used to investigate the effect of long runs of consecutive 1s on the thermal wavelength drift of the lasers. Time-resolved spectroscopy measurements have been performed on four prototype DFB laser packages at a modulation frequency of 30 Mbit/s (one eightieth of the system line rate of 2.5 GHz) in order to simulate the effect of runs of forty consecutive 1s. Results at various submount operating temperatures are considerably better than expected, being no worse than 0.05 nm, the approximate limit of resolution of the spectrometer. This test equipment will be used to set the laser wavelength to the centre of each channel.

4.4 Star coupler

Work has concentrated on improving the repeatability of the fabrication process for fibre couplers. A simple numerical model for the wavelength response of N × N star couplers has been implemented and will be used to optimise placement of devices within the matrix to achieve uniformity of outputs.

In May, wavelength-flattened 2 × 2 all-fibre couplers with a coupling ratio of 0.5 ±0.015 between 1510 nm and 1565 nm and loss <0.1 dB were fabricated. Four couplers were later assembled into a 4 × 4 coupler. The 4 × 4 coupler shows a mean path loss variation of 0.32 dB over the range 1500 - 1560 nm which was agreed for the system specification. This result shows that the specification for a 16 × 16 coupler can be met. A report has been written on the fabrication technique for 16 × 16 couplers. By the end of the year, half of an unpackaged 16 × 16 star coupler had been completed; 2 × 2 couplers were being produced with reduced insertion loss and wavelength flatness over a sufficient range was routinely achieved.

A study of architectures for planar waveguide star couplers has been carried out and initial planar waveguide fabrication has started. An electron beam mask has been fabricated for 2 × 2 mixers based on directional couplers and a first iteration has been made to reduce difficulties with photolithography and to improve waveguide-fibre coupling. Devices made from the first-iteration mask are being assessed and fibre-waveguide coupling is being optimised: preliminary results have already shown that fibre-waveguide-fibre losses less than 5 dB are achievable. Reports have been prepared describing planar waveguide technology and specifications for the 16 × 16 star coupler. Fig. 4 shows the layout of directional couplers on the substrate.



Courtesy of GEC Hirst Research Centre

Fig. 4 - Geometric layout of planar waveguide directional couplers.

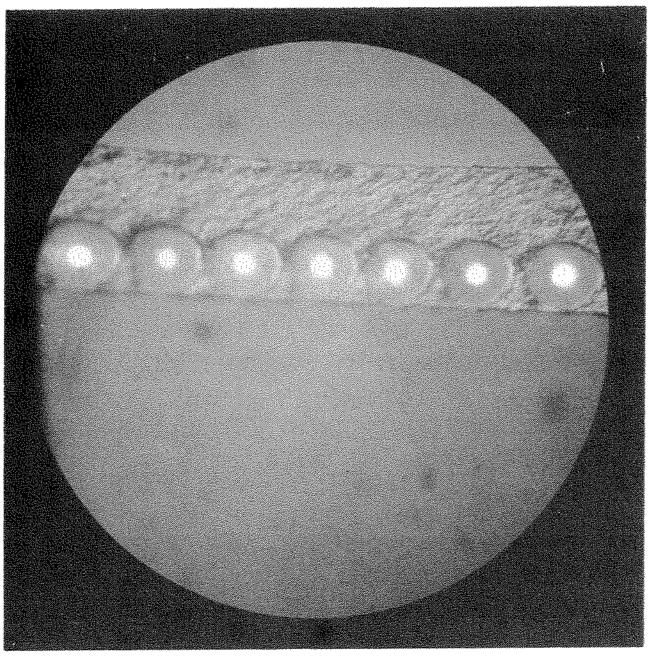
4.5 Optical demultiplexer

Design studies have been carried out on fibre-coupled, diode-coupled and planar waveguide optical demultiplexers. These studies have allowed a number of optical parameters to be agreed. In particular it has been confirmed that 4 nm is a suitable channel spacing: from considerations of the precision with which the temperature (and hence the wavelength) of the laser can be controlled, the expected wavelength

drift over the system life, and the absolute wavelength measurement uncertainty, the wavelength of any channel can only be guaranteed to be maintained to within ±0.7 nm of its nominal centre wavelength; a wavelength spacing of 4 nm is reasonable, taking account of the expected optical crosstalk between channels in the demultiplexers. In the case of the fibre-coupled demultiplexer, it has been shown that the crosstalk will be sufficiently low with 50 μm core output fibres.

A study of polarisation losses in the optical demultiplexer has shown that an allowance of 2 dB will be adequate.

Different fibre arrays have been manufactured with sixteen fibres out. The position of each optical fibre was measured. The maximum difference between real and nominal positions of the fibres gives the uncertainty on the centre wavelength of each channel (taking into account the dispersion in focal plane). This uncertainty was in all cases much less than the passband of each channel. Fig. 5 shows a fibre array used in a demultiplexer with a large number of channels. The latest results on the manufacture of the optical demultiplexer show that it will be possible to increase the passband in order to include this uncertainty and to accommodate the laser drift without risk of crosstalk between adjacent channels.



Courtesy of Jobin-Yvon

Fig. 5 - Photograph of a fibre array used in a fibre-coupled demultiplexer with a large number of channels.

Measurements and detailed calculations on prototype fibre-coupled demultiplexers confirm that the Stimax[4] configuration will fulfil the R1036 specification; manufacturing of the final Stimax 16-channel demultiplexer has now begun.

A sub-project meeting was held to discuss the need for a planar waveguide array to couple light from the lens onto the photodiode array. It was decided that the waveguide array will not be needed at this time.

A grating demultiplexer with 4 nm channel separation and a 10-fibre array to simulate a 40/160 μm diode array has been set up and studied. The maximum optical crosstalk seen by one central channel from the 15 other channels (in an array of 16) was estimated to be −29 dB (the system specification is −20 dB). The insertion loss of this demultiplexer was less than 3 dB. Measurements of return loss in a breadboard diode-coupled demultiplexer have shown that the return loss is almost entirely due to the reflection from the cleaved end of the single-mode input fibre. The worst return loss measured was −16 dB, which is acceptable in the WTDM system.

A number of gratings have been assessed for polarisation sensitivity and values of less than 1 dB have been observed over the system wavelength range of 1500 to 1560 nm.

Processing of the first batch of array wafers has been completed by RACE Project 1027. A four-element diode array was received on schedule and successfully mounted on the breadboard grating demultiplexer for initial assessment. The diode elements were of the interdigitated type with an active area of 40 μm × 40 μm and with a pitch of 160 μm. However, further work showed that a larger active area, of the order of 100 μm × 40 μm with a pitch of 167 μm, was needed to accommodate the required channel passband of ±0.7 nm. A 16-element array with this larger area and pitch was delivered ahead of schedule by R1027: preliminary evaluation of this photodetector array mounted in the breadboard demultiplexer has shown much poorer isolation than predicted from fibre measurements. Experiments have shown that the poor isolation is within the photodetector array chip and a number of wafer processing modifications are being investigated. Measurements on the first modified array show improved isolation values, just within the specification requirements. A photograph of the prototype demultiplexer used in these experiments is shown in Fig. 6.

A literature search has been carried out as a first step towards designing an integrated optical demultiplexer using planar waveguide technology and a report has been written.

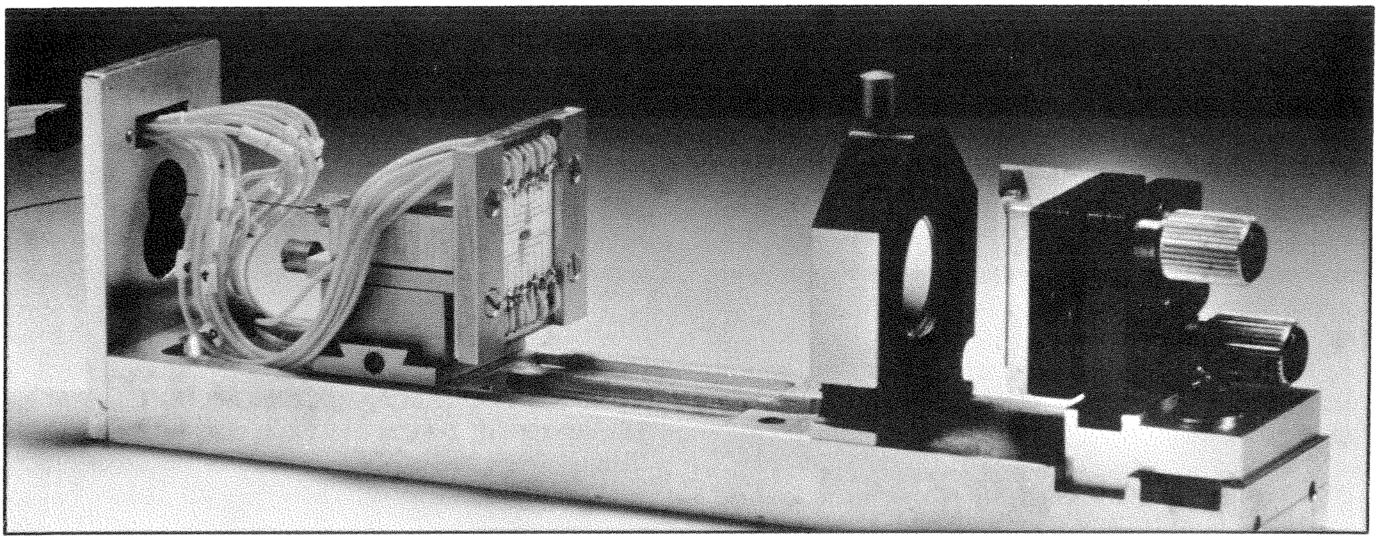


Fig. 6 - The prototype diode-coupled optical demultiplexer. Courtesy of STC Technology

4.6 Optical receiver

Initial studies were carried out on the specifications and achievable performances of optical receivers currently available or under development. The sensitivity of an optical receiver using a PIN photodiode was calculated for the agreed line rate (2.5 Gbit/s) and BER (10^{-10}). Calculation of the optical power budget showed that the PIN diode receiver, with a network sensitivity of −28 dBm, would not meet system budget requirements. The sensitivity of a receiver in a network using an APD was therefore calculated and found to be −34 dBm. When inserted in the latest optical power budget this figure shows a satisfactory power margin of 6.9 dB.

An essential part of the receiver is a circuit to regenerate the 2.5 GHz clock. As noted in Section 2.1, it was expected when the Project was planned that this technology would be available from outside; the corresponding work package was therefore deleted from the Technical Annex. Contacts were made with British Telecom Research Laboratories and the Technical University of Denmark, but no solutions were found to the problem of clock recovery. Active PLL devices cannot generate clocks for long strings of 1s or 0s and the Project will need a passive device based on a filter. Towards the end of the year, the renewal of the contract was negotiated with RACE Central Office and a modest increase in funding was granted, sufficient to include clock regeneration and some other desirable improvements in future work on the Project.

4.7 Selector electronics

Different approaches for realising the selector electronics matrix with available components have been studied; a report on this study has been written. Contacts have been made with R1013 as mentioned in Section 3.2 and with other organizations outside RACE. Although these approaches are still being considered, a new contact with an Esprit 2 project has recently been established; it is hoped that this project will be able to supply packaged and tested integrated circuits to make up a 16 × 16 routing matrix.

4.8 IBCN interface

Following publication of the first report on the broadband user-network interface by R1044 group 2.1, a report was prepared comparing suitable options for the WTDM system IBCN.

4.9 Control

A study of the bearer service structure was completed and a report was written. For use in the WTDM BCPN a bearer service structure that allows linking of connections with implicit synchronization is chosen. The multiplexing structure given in CCITT Recs G.707, 708, and 709 has been investigated and a channel for network control data has been identified. Additionally an interface between the control system and the selector hardware is being defined.

The textual description and the definition in SDL of layers 1, 2, and 3 of the control protocol have been completed. These documents comprise the description of the internal BCPN protocol (as opposed to the IBCN-BCPN and BCPN-terminal protocol). The BCPN protocol is designed with the ISDN protocols in mind and in a highly modular fashion to allow maximum flexibility and easy upgrading. This is needed to adapt to the formal IBCN standards (also based on ISDN) when they become available and to maximize the usability as a testbed for IBCN implementations. The textual description describes the functions to be performed to establish and maintain links between the nodes of the BCPN and to perform

the identification of users and allocation of resources, as well as the necessary management of these functions. The definition in SDL is a formal specification which maintains a stringent separation between the layers of the OSI model and the functions within these layers.

The structure is as follows:

The physical layer is specified as part of the electrical and optical specification of the network. Only the service access points are described.

The link layer contains six processes. The three lower level processes perform interfacing and multiplexing to the service access points in the physical layer as well as the mapping of the physical multi-loop control network into a logical complete mesh network. The three higher level processes perform the establishment and management of the links between the nodes, and the error protection of these links; they also perform the interfacing to the network layer.

The network layer contains two blocks, a call control block and a management block. The call control block contains four processes to perform the initiation of call control processes and the mapping of these calls onto the link layer service access points. The management block contains five processes and performs the resource and user allocation together with the management blocks of other nodes. In this block the processes to interface to the control console and to the selection hardware are also incorporated.

4.10 Contribution to standardization bodies

The ideas described in the report on the bearer service structure were presented in a somewhat modified format (to suit the requirements of CEPT documents) to NA 5 of CEPT in the Den Haag meeting (May 7 to May 11 1988) in the Service Aspects sub-group. This resulted in the formulation of a question for the next study period of CCITT into the effects of synchronization and control of multi-bearer teleservices.

A description of the BCPN and its application in television studio centres was presented to the CCIR IWP 11/7 at its meeting in Toronto in October 1988.

4.11 Other publications

A general description of the Project, edited from the Technical Annex, was approved by the Partners for publication outside the Project. It has been widely distributed to interested parties within and outside RACE.

A description of the Project and of the application of the WTDM system to the routing of signals in a broadcaster's premises is given in a paper presented at the 12th International Broadcasting Convention in Brighton, UK on 25th September and published in the Convention publication. This paper was supported by a demonstration of wavelength multiplexing on the BBC stand at the accompanying exhibition.

5. CONCLUSIONS

Work in the Project is proceeding as planned. To date all the scheduled deliverables (both reports and devices) have been produced on time with scope as proposed and with satisfactory contents. Man-month estimates for the Project so far have proved very accurate. The technical problems that have arisen have been solved in a spirit of cooperation. The EEC contract, originally granted for only one year, has been renewed for a further two years. Sufficient extra funds have been allocated to allow the reincorporation of clock recovery, which was cut from the original proposal in order to meet cash limits, and to ensure that multiplexing techniques should conform to the new CCITT draft Recommendations.

The System Specification, the major deliverable this year, represents a solid foundation for the work of the rest of the Project. The expertise of the Partners ensures that the BCPN that has been specified could be realised in production. Thus the test bed that will be constructed will not be just a one-off laboratory demonstration but will validate the concept of a BCPN that will encourage large-scale use of the IBCN.

6. REFERENCES

1. Commission of the European Communities, 1988. RACE '88 — The RACE Programme in 1988. CEC document OTR-112.

2. OLIPHANT, A., MARSDEN, R.P., and ZUBRZYCKI, J.T., 1987. An optical routing system for tomorrow's television studio centres. *SMPTE Journal*, July 1987, pp 660-666.

3. Commission of the European Communities, 1988. RACE Workplan '89. CEC document OTR200.

4. LAUDE, J-P and LERNER, J.M., 1984. Wavelength division multiplexing/demultiplexing (WDM) using diffraction gratings. SPIE, Vol. 503, Application, Theory, and Fabrication of Periodic Structures, pp 22-28.